



AQA 7405

Alkanes

FRACTIONS • CRACKING • COMBUSTION • RADICAL SUBSTITUTION

ORIGINAL EXAM QUESTIONS | TEST IT → EXAM STYLE → HARDER MIXED → STRETCH

TEST IT	EXAM STYLE	HARDER MIXED	STRETCH
8	8	4	2

22 QUESTIONS MASTERED | 198 TOTAL MARKS

Mapped to AQA Chemistry 7405 sections 3.3.2.1–3.3.2.4

Specification checked 3 October 2026

How to use this pack [START HERE](#)

- 1 Read the command word** State is concise. Explain must link cause to effect. Calculate must show a chemically valid route and unit.
- 2 Use exact particle language** Fractions are mixtures. Cracking changes molecules. Boiling overcomes London (van der Waals) forces between molecules.
- 3 Audit every equation** Conserve every atom. In radical steps, retain every radical dot and check whether a radical is created, regenerated or removed.
- 4 Use the space like an exam** Questions give unscaffolded working space. Show enough stages for the marks and keep final answers easy to identify.

Specification route

AQA section	Assessed in this pack
3.3.2.1	Saturated hydrocarbons; petroleum; fractional distillation and boiling ranges.
3.3.2.2	C–C bond breaking; thermal and catalytic cracking; product demand and economics.
3.3.2.3	Complete/incomplete combustion; engine pollutants; converters; sulfur dioxide removal.
3.3.2.4	Methane chlorination by initiation, propagation and termination; valid application to larger alkanes.

AQA BOUNDARY No alkene reaction mechanism, halogenoalkane chemistry or aromatic reaction chemistry is required. Radical equations use ordinary reaction arrows; AQA does not require curly arrows for free-radical mechanisms.

SECTION A TEST IT

Secure the exact definitions, equations and process distinctions before the longer questions.

QUESTION 1 | TEST IT

(a) Define the term hydrocarbon. (1 mark)

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(b) State what is meant by saturated when describing an alkane. (1 mark)

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(c) State the general formula of an open-chain alkane. (1 mark)

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(d) Give the molecular formula of the open-chain alkane containing nine carbon atoms. (1 mark)

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(e) Explain why C_6H_{12} cannot be an open-chain alkane and why this formula alone does not prove that the compound contains a C=C bond. (2 marks)

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QUESTION 2 | TEST IT

The four hydrocarbons are pentane, 2-methylbutane, 2,2-dimethylpropane and heptane.

(a) Place the three C_5H_{12} isomers in order of increasing boiling point. (1 mark)

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(b) Explain the order in part (a) using molecular shape and intermolecular attractions. (3 marks)

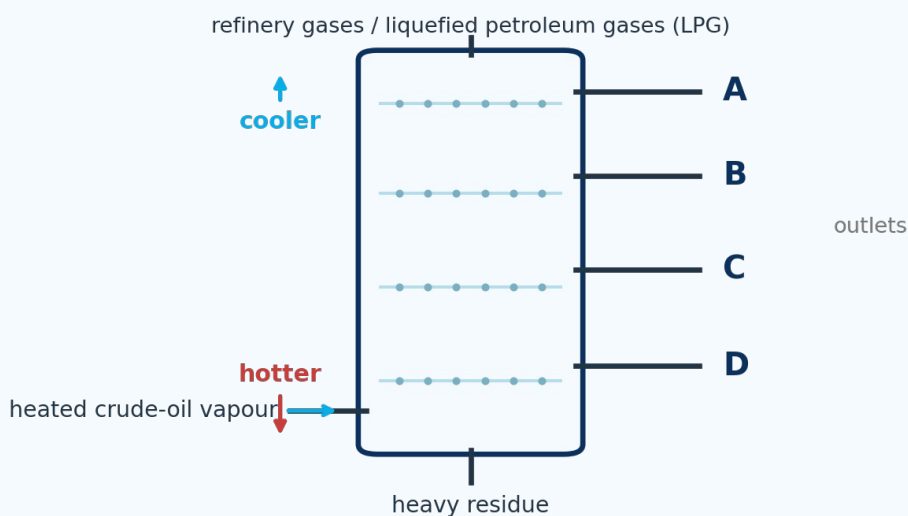
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(c) Explain why heptane has a higher boiling point than pentane. (2 marks)

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QUESTION 3 | TEST IT

Figure 1 represents part of a refinery fractionating column. The labelled outlets collect different liquid fractions.

FIGURE 1 FRACTIONAL DISTILLATION OF PETROLEUM

(a) State what is meant by a fraction.

(2 marks)

(b) Explain how the temperature gradient separates the vaporised hydrocarbons into fractions.

(3 marks)

(c) State which labelled outlet collects the liquid fraction with the lowest boiling range.

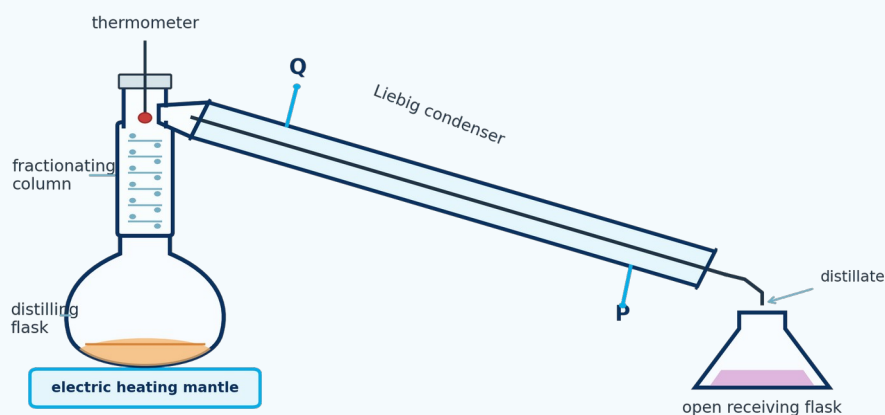
(1 mark)

(d) Explain why a collected fraction is not a pure compound.

(1 mark)

QUESTION 4 | TEST IT

Figure 2 shows laboratory fractional distillation. P and Q are the two water connections on the condenser.

FIGURE 2 LABORATORY FRACTIONAL DISTILLATION

(a) State the correct position of the thermometer bulb and explain what temperature it measures.

(2 marks)

(b) State which connection, P or Q, is the water inlet. Explain your choice. (2 marks)

(c) Explain how the fractionating column improves the separation. (2 marks)

QUESTION 5 | TEST IT

(a) Define cracking in terms of molecules and bonds. (2 marks)

(b) Name the cracking process used to obtain a high percentage of alkenes. State its pressure and temperature conditions. (3 marks)

(c) State the catalyst used in catalytic cracking. (1 mark)

QUESTION 6 | TEST IT

Each equation represents one possible cracking route.



(a) Deduce the molecular formula of X. (2 marks)



(b) Deduce the value of a. (2 marks)

(c) Write a balanced equation for cracking $\text{C}_{22}\text{H}_{46}$ to form $\text{C}_{10}\text{H}_{22}$ and two molecules of one alkene. (1 mark)

(d) Give two economic reasons for cracking surplus long-chain hydrocarbons. (2 marks)

QUESTION 7 | TEST IT

(a) Write the balanced equation for the complete combustion of hexane, C_6H_{14} . Use the smallest whole-number coefficients. (3 marks)

(b) Write a balanced equation for incomplete combustion of butane, C_4H_{10} , forming carbon monoxide and water only. (2 marks)

(c) Write a balanced equation for incomplete combustion of propane, C_3H_8 , forming carbon and water only. (2 marks)

QUESTION 8 | TEST IT

(a) Define a free radical. (1 mark)

(b) Explain what happens to the bonding pair of electrons during homolytic fission. (2 marks)

(c) Write the initiation equation for chlorination of methane and state the condition needed. (2 marks)

(d) Explain why $\text{Cl}\cdot$ and Cl^- do not represent the same species. (2 marks)

SECTION B EXAM STYLE

Apply the specification in linked AQA-style questions with unfamiliar data and unscaffolded working space.

QUESTION 9 | EXAM STYLE

A refinery separates petroleum into four fractions. The data are invented for this question.

Fraction	Boiling range / °C	Supply / units	Demand / units
A	25–70	18	30
B	70–180	40	55
C	180–300	50	45
D	300–420	65	35

(a) State which fraction is collected highest in the column. (1 mark)

(b) Explain your answer to part (a) using boiling range and the temperature gradient. (3 marks)

(c) Calculate the surplus of fraction D and the shortage of fraction B. (2 marks)

(d) Name the cracking process most suitable for converting some of D into motor fuel. (1 mark)

(e) Explain why fractional distillation is a physical process.

(1 mark)

QUESTION 10 | EXAM STYLE

Two industrial cracking trials give the following product patterns.

Trial	Conditions	Main product pattern
K	high temperature; high pressure; no catalyst	high percentage of alkenes; mainly straight-chain alkanes
L	high temperature; slight pressure; zeolite	branched-chain motor-fuel alkanes and aromatic hydrocarbons

(a) Identify the type of cracking used in K and in L.

(2 marks)

(b) Choose the trial that is more suitable for making alkene feedstock. Justify your choice.

(2 marks)

(c) Choose the trial that is more suitable for increasing motor-fuel production. Justify your choice.

(2 marks)

(d) Explain the role of the zeolite in trial L.

(2 marks)

QUESTION 11 | EXAM STYLE

In this cracking route, X is an open-chain alkene.



(a) Deduce the molecular formula of X. Show an atom check.

(2 marks)

(b) State the homologous series to which X belongs and identify the structural feature responsible.

(2 marks)

(c) Write a balanced equation for cracking $\text{C}_{15}\text{H}_{32}$ to form C_7H_{16} and two molecules of one alkene.

(2 marks)

(d) Explain why an industrial cracking unit produces a mixture rather than only the products in one displayed equation.

(1 mark)

(e) Explain why this mixture can still be economically valuable.

(2 marks)

QUESTION 12 | EXAM STYLE

Exhaust-gas measurements were made before and after a catalytic converter reached its working temperature.

Pollutant	Before / mmol dm^{-3}	After / mmol dm^{-3}
CO	12.0	2.40
NO	7.50	1.50
unburned hydrocarbons	3.20	0.80

- (a) Calculate the percentage decrease in CO concentration. (2 marks)

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- (b) Write a balanced equation showing CO and NO converted into CO_2 and N_2 . (2 marks)

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- (c) In the equation from part (b), state which pollutant is oxidised and which is reduced. (2 marks)

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- (d) Explain why pollutant conversion is less effective during a cold start. (2 marks)

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- (e) State one important emission that the catalytic converter does not eliminate. (1 mark)

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QUESTION 13 | EXAM STYLE

A power station burns a fuel containing sulfur impurities. In one period, 6.41 kg of SO_2 is removed using calcium carbonate. Assume the reaction is complete. $M_r(\text{SO}_2) = 64.1$ and $M_r(\text{CaCO}_3) = 100.1$.

- (a) Explain how sulfur dioxide forms even though a pure alkane contains no sulfur. (1 mark)

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- (b) Explain why calcium carbonate can remove sulfur dioxide from flue gas. (2 marks)

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- (c) Write the equation for calcium carbonate reacting with sulfur dioxide to form calcium sulfite. (1 mark)

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- (d) Calculate the minimum mass, in kg, of calcium carbonate required. (4 marks)

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- (e) Explain why calcium carbonate is a reagent and not a catalyst in this process. (1 mark)

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QUESTION 14 | EXAM STYLE

Methane reacts with chlorine in ultraviolet light to form chloromethane as one product.

- (a) Write the overall equation for formation of chloromethane. (1 mark)

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(b) Write the initiation equation and state the role of ultraviolet light. (2 marks)

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- (c) Write the two propagation equations. Show every radical dot. (4 marks)

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- (d) Write two different termination equations possible in this reaction. (2 marks)

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- (e) Explain why the two propagation steps allow a chain reaction to continue. (2 marks)

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QUESTION 15 | EXAM STYLE

Ethane reacts with chlorine under ultraviolet light. The desired product is chloroethane.

- (a) Write the two propagation equations that form chloroethane. (4 marks)

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- (b) Identify the organic radical intermediate and the radical that is regenerated. (2 marks)

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- (c) Write a termination equation in which two ethyl radicals form butane. (1 mark)

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- (d) Explain why the reaction mixture can contain products with more than one chlorine atom. (2 marks)

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QUESTION 16 | EXAM STYLE

A student proposes the following steps for chlorination of methane. Some descriptions are incorrect.

Step	Student equation or description
I	$\text{Cl}_2 \rightarrow \text{Cl}^+ + \text{Cl}^-$ (initiation)
II	$\text{Cl}\cdot + \text{CH}_4 \rightarrow \text{HCl} + \text{CH}_3\cdot$ (propagation)
III	$\text{CH}_3\cdot + \text{Cl}\cdot \rightarrow \text{CH}_3\text{Cl}$ (propagation)
IV	$\text{CH}_3\text{Cl} + \text{Cl}_2 \rightarrow \text{CH}_2\text{Cl}_2 + \text{HCl}$ (one propagation step)

(a) Correct step I, state the condition needed, and name the type of bond fission. (3 marks)

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(b) Give the correct classification of step III and explain your answer. (2 marks)

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(c) Replace step IV with the two propagation equations that form dichloromethane from chloromethane. (4 marks)

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SECTION C HARDER MIXED

Select the route yourself, combine ideas and use quantitative or mechanistic evidence without prompts.

QUESTION 17 | HARDER MIXED

A refinery has the following weekly supply and demand. The data are invented.

Fraction	Boiling range / °C	Supply / units	Demand / units
R	35–90	20	34
S	90–180	42	51
T	220–340	48	40
U	>360	70	35

(a) Identify the fraction collected highest in the column and explain your answer. (3 marks)

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(b) Calculate the combined shortage of R and S and the surplus of U.

(2 marks)

(c) Recommend a process for converting some U into motor fuel. State the catalyst and the relevant product type. (3 marks)

(d) Write a balanced equation for $C_{19}H_{40}$ cracking to form C_7H_{16} and two molecules of C_6H_{12} .

(1 mark)

(e) Explain why fractional distillation must not be described as the first stage of the cracking reaction.

(2 marks)

QUESTION 18 | HARDER MIXED

A 0.100 mol sample of heptane, C_7H_{16} , burns with restricted oxygen. Of all carbon atoms, 70.0% form CO_2 , 20.0% form CO and 10.0% form solid carbon. Assume all hydrogen forms water.

(a) Write the equation for complete combustion of heptane.

(2 marks)

(b) Calculate the amounts, in mol, of CO_2 , CO and solid carbon formed in the restricted-oxygen experiment. (3 marks)

(c) Calculate the amount, in mol, of water formed.

(1 mark)

(d) Calculate the total amount, in mol, of O_2 consumed.

(3 marks)

(e) Explain why CO and soot form, and state one harmful effect of each.

(3 marks)

QUESTION 19 | HARDER MIXED

Propane reacts with chlorine under ultraviolet light. Consider separately the pathways forming 1-chloropropane and 2-chloropropane.

(a) Write the initiation equation and state the condition. (2 marks)

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(b) Write both propagation equations for formation of 1-chloropropane. Use $\text{CH}_3\text{CH}_2\text{CH}_2\cdot$ for the organic radical. (4 marks)

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(c) Write both propagation equations for formation of 2-chloropropane. Use $\text{CH}_3\dot{\text{C}}\text{HCH}_3$ for the organic radical. (4 marks)

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(d) Explain why both monochloro products can form even before further substitution is considered. (2 marks)

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QUESTION 20 | HARDER MIXED

A cracking unit processes 1.00 mol of $\text{C}_{18}\text{H}_{38}$. In a simplified model, 70.0% of the molecules follow route A and 30.0% follow route B.



(a) Calculate the amount, in mol, of each of the four products formed. (4 marks)

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(b) Calculate the total amount, in mol, of alkene molecules formed. (1 mark)

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(c) Use the amounts from part (a) to show that 18.0 mol of carbon atoms are present in the products. (2 marks)

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(d) The refinery wants alkene feedstock. Recommend a cracking process and state its pressure and temperature conditions. (3 marks)

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(e) If the priority changed to branched-chain motor fuels, name the preferred process and catalyst. (2 marks)

SECTION D STRETCH / SYNOPTIC

Deduce what is not stated, connect prior quantitative skills and audit complete chains of reasoning.

QUESTION 21 | STRETCH / SYNOPTIC

A 0.580 g sample of an unknown open-chain alkane burns completely to form 1.760 g CO₂ and 0.900 g H₂O. A_r: H = 1.0, C = 12.0, O = 16.0.

(a) Use the combustion data to determine the empirical formula of the alkane. (3 marks)

(b) Use the general formula of an open-chain alkane to deduce its molecular formula. (2 marks)

(c) Give the systematic name of the alkane. (1 mark)

(d) Write its complete combustion equation using the smallest whole-number coefficients. (2 marks)

(e) Write a balanced cracking equation in which one molecule of this alkane forms ethane and ethene. (2 marks)

(f) Explain why this alkane has a lower boiling point than octane. (3 marks)

QUESTION 22 | STRETCH / SYNOPTIC

The equations below are all possible steps or linked steps in chlorination of methane under ultraviolet light.

Step	Equation
I	$\text{Cl}_2 \rightarrow 2\text{Cl}\cdot$
II	$\text{Cl}\cdot + \text{CH}_4 \rightarrow \text{HCl} + \text{CH}_3\cdot$
III	$\text{CH}_3\cdot + \text{Cl}_2 \rightarrow \text{CH}_3\text{Cl} + \text{Cl}\cdot$
IV	$\text{CH}_3\cdot + \text{Cl}\cdot \rightarrow \text{CH}_3\text{Cl}$
V	$\text{Cl}\cdot + \text{CH}_3\text{Cl} \rightarrow \text{HCl} + \cdot\text{CH}_2\text{Cl}$
VI	$\cdot\text{CH}_2\text{Cl} + \text{Cl}_2 \rightarrow \text{CH}_2\text{Cl}_2 + \text{Cl}\cdot$

(a) Classify steps I, II, III and IV as initiation, propagation or termination. (4 marks)

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(b) Explain how ultraviolet light causes step I and state what happens to the bonding pair. (2 marks)

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(c) Add steps II and III, cancel the intermediates and write the overall equation. (2 marks)

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(d) Identify the organic intermediate and the radical regenerated in steps II and III. (2 marks)

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(e) Use steps V and VI to explain why chlorination can form a mixture of substitution products. (2 marks)

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(f) State how the reactant ratio can favour chloromethane and explain why a pure product is still not guaranteed. (2 marks)

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QUESTIONS END HERE • ANSWERS BEGIN ON THE NEXT PAGE



AQA 7405

Alkanes

FRACTIONS • CRACKING • COMBUSTION • RADICAL SUBSTITUTION

ANSWERS & MARK SCHEME | FULLY WORKED • PRECISELY MARKED • BUILT FOR IMPROVEMENT

TEST IT	EXAM STYLE	HARDER MIXED	STRETCH
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SECTION A

TEST IT ANSWERS

Award marks only for chemically precise statements, balanced equations and visible radical notation.

QUESTION 1 | TEST IT

6 marks

- (a) A compound containing carbon and hydrogen only. [1]
(b) It contains only single carbon–carbon bonds. [1]
(c) C_nH_{2n+2} . [1]
(d) C_9H_{20} . [1]
(e) For $n = 6$, an open-chain alkane would be C_6H_{14} , so C_6H_{12} does not fit C_nH_{2n+2} [1]. C_6H_{12} could contain a ring rather than a C=C bond, so the molecular formula alone is not conclusive [1].

QUESTION 2 | TEST IT

6 marks

- (a) 2,2-dimethylpropane < 2-methylbutane < pentane. [1]
(b) The three molecules have the same molecular formula/electron count [1]. Greater branching makes a molecule more compact and reduces effective surface contact [1], so the overall London (van der Waals) forces are weaker and less energy is needed to separate the molecules [1].
(c) Heptane has more electrons/a larger electron cloud than pentane [1], giving stronger overall London (van der Waals) forces between its molecules and a higher boiling point [1].
COMMON ERROR Do not explain boiling point by breaking C–C or C–H covalent bonds.

QUESTION 3 | TEST IT

7 marks

- (a) A fraction is a mixture of hydrocarbons [1] with similar boiling points/collected over a boiling range [1].
(b) Most crude oil is vaporised before entering the lower column [1]. The column is hot at the bottom and cooler at the top, so vapours cool as they rise [1]. Hydrocarbons condense when the local temperature falls below their boiling point, with higher-boiling components condensing lower down and lower-boiling components higher up [1].
(c) A. [1]
(d) Each outlet collects several hydrocarbons with similar, not identical, boiling points [1].

QUESTION 4 | TEST IT

6 marks

- (a) The bulb must be level with the entrance to the side arm [1], so it measures the temperature of vapour entering the condenser [1].
(b) P is the water inlet [1]. Water enters at the lower connection and leaves at the upper connection, keeping the condenser jacket full for effective cooling [1].
(c) The fractionating column provides repeated condensation and vaporisation [1], enriching the rising vapour in the more volatile/lower-boiling component [1].

QUESTION 5 | TEST IT

6 marks

- (a) Cracking breaks larger hydrocarbon molecules into smaller molecules [1] by breaking carbon–carbon bonds [1].
(b) Thermal cracking [1]; high pressure [1] and high temperature [1].

(c) A zeolite. [1]

QUESTION 6 | TEST IT**7 marks**(a) Carbon remaining = $17 - 9 = 8$ and hydrogen remaining = $36 - 20 = 16$, so $X = C_8H_{16}$. [2](b) Carbon: $20 - 12 = 8$, so $4a = 8$ and $a = 2$; the hydrogen check is $26 + 2(8) = 42$. [2](c) $C_{22}H_{46} \rightarrow C_{10}H_{22} + 2C_6H_{12}$. [1]

(d) Any two: convert surplus/low-demand heavy fractions into products in greater demand; make smaller molecules useful as fuels; make alkenes used as chemical/polymer feedstock; increase the value of the product mixture. [1 each]

COMMON ERROR A coefficient multiplies the whole formula; subscripts must not be altered to balance an equation.**QUESTION 7 | TEST IT****7 marks**(a) $2C_6H_{14} + 19O_2 \rightarrow 12CO_2 + 14H_2O$. Correct carbon and hydrogen coefficients [1]; correct oxygen coefficient [1]; smallest whole-number set [1].(b) $2C_4H_{10} + 9O_2 \rightarrow 8CO + 10H_2O$. [2](c) $C_3H_8 + 2O_2 \rightarrow 3C + 4H_2O$. [2]**QUESTION 8 | TEST IT****7 marks**

(a) A species containing an unpaired electron. [1]

(b) The covalent bond breaks [1] and each bonded atom receives one electron from the shared pair [1].

(c) $Cl_2 \rightarrow 2Cl\cdot$ [1]; ultraviolet light [1].(d) $Cl\cdot$ is a neutral chlorine atom with an unpaired electron [1], whereas Cl^- is a negatively charged ion with an extra electron [1].**SECTION B****EXAM STYLE ANSWERS***The marking points show the chain of reasoning expected in a full AQA-style response.***QUESTION 9 | EXAM STYLE****8 marks**

(a) A. [1]

(b) A has the lowest boiling range [1]. It remains as vapour through warmer parts of the column and rises furthest [1], then condenses in the cooler upper region [1].

(c) Surplus of D = $65 - 35 = 30$ units [1]. Shortage of B = $55 - 40 = 15$ units [1].

(d) Catalytic cracking. [1]

(e) Existing hydrocarbons are separated by boiling point and no new substances/covalent bonds are formed [1].

QUESTION 10 | EXAM STYLE**8 marks**

(a) K is thermal cracking [1]; L is catalytic cracking [1].

(b) K [1], because thermal cracking gives a high percentage of alkenes [1].

(c) L [1], because catalytic cracking is used mainly to produce motor fuels, including branched-chain alkanes [1].

(d) The zeolite provides an alternative reaction pathway with lower activation energy [1] and is not used up overall [1].

QUESTION 11 | EXAM STYLE**9 marks**(a) Carbon remaining = $24 - 10 - 8 = 6$; hydrogen remaining = $50 - 20 - 18 = 12$, so $X = C_6H_{12}$. [2]

(b) X is an alkene [1] containing a carbon-carbon double bond [1].

(c) $C_{15}H_{32} \rightarrow C_7H_{16} + 2C_4H_8$. [2]

(d) Different C-C bonds can break and different smaller product combinations can form [1].

(e) The mixture contains smaller fuel molecules [1] and alkene feedstock for chemical manufacture/polymers [1].

QUESTION 12 | EXAM STYLE**9 marks**(a) Percentage decrease = $((12.0 - 2.40) \div 12.0) \times 100 = 80.0\%$. Correct decrease [1]; percentage [1].(b) $2CO + 2NO \rightarrow 2CO_2 + N_2$. [2](c) CO is oxidised to CO_2 [1]; NO is reduced to N_2 [1].

(d) The catalyst is below its working temperature [1], so the catalysed reactions are too slow/fewer molecules react before leaving the converter [1].

(e) Carbon dioxide. [1]

QUESTION 13 | EXAM STYLE**9 marks**(a) The fuel contains sulfur-containing impurities that form SO_2 on combustion [1].(b) SO_2 is an acidic oxide [1] and $CaCO_3$ is basic/reacts with acidic oxides [1].(c) $CaCO_3 + SO_2 \rightarrow CaSO_3 + CO_2$. [1](d) $6.41 \text{ kg} = 6410 \text{ g}$ [1]. $n(SO_2) = 6410 \div 64.1 = 100 \text{ mol}$ [1]. The equation ratio $CaCO_3 : SO_2$ is 1 : 1, so $n(CaCO_3) = 100 \text{ mol}$ [1]. Mass = $100 \times 100.1 = 10\,010 \text{ g} = 10.0 \text{ kg}$ to three significant figures [1].(e) $CaCO_3$ is consumed/chemically changed in the reaction rather than regenerated [1].

QUESTION 14 | EXAM STYLE

11 marks

- (a) $\text{CH}_4 + \text{Cl}_2 \rightarrow \text{CH}_3\text{Cl} + \text{HCl}$. [1]
 (b) $\text{Cl}_2 \rightarrow 2\text{Cl}\cdot$ [1]. Ultraviolet light supplies energy for homolytic fission of the Cl–Cl bond [1].
 (c) $\text{Cl}\cdot + \text{CH}_4 \rightarrow \text{HCl} + \text{CH}_3\cdot$ [2]. $\text{CH}_3\cdot + \text{Cl}_2 \rightarrow \text{CH}_3\text{Cl} + \text{Cl}\cdot$ [2]. Each equation must conserve atoms and show one radical on each side.
 (d) Any two: $\text{Cl}\cdot + \text{Cl}\cdot \rightarrow \text{Cl}_2$; $\text{CH}_3\cdot + \text{Cl}\cdot \rightarrow \text{CH}_3\text{Cl}$; $\text{CH}_3\cdot + \text{CH}_3\cdot \rightarrow \text{C}_2\text{H}_6$. [1 each]
 (e) A chlorine radical is consumed in the first propagation step [1] and regenerated in the second, so it can react with another methane molecule [1].

QUESTION 15 | EXAM STYLE

9 marks

- (a) $\text{Cl}\cdot + \text{C}_2\text{H}_6 \rightarrow \text{HCl} + \text{C}_2\text{H}_5\cdot$ [2]. $\text{C}_2\text{H}_5\cdot + \text{Cl}_2 \rightarrow \text{C}_2\text{H}_5\text{Cl} + \text{Cl}\cdot$ [2].
 (b) $\text{C}_2\text{H}_5\cdot$ is the organic intermediate [1]; $\text{Cl}\cdot$ is regenerated [1].
 (c) $\text{C}_2\text{H}_5\cdot + \cdot\text{C}_2\text{H}_5 \rightarrow \text{C}_4\text{H}_{10}$, butane. [1]
 (d) Chloroethane still contains C–H bonds that can undergo further substitution [1], so dichloro and more highly substituted products can form [1].

QUESTION 16 | EXAM STYLE

9 marks

- (a) $\text{Cl}_2 \rightarrow 2\text{Cl}\cdot$ [1]. The bond breaks by homolytic fission [1], initiated by ultraviolet light [1].
 (b) Step III is termination [1] because two radicals combine and no radical product is formed [1].
 (c) $\text{Cl}\cdot + \text{CH}_3\text{Cl} \rightarrow \text{HCl} + \cdot\text{CH}_2\text{Cl}$ [2]. $\cdot\text{CH}_2\text{Cl} + \text{Cl}_2 \rightarrow \text{CH}_2\text{Cl}_2 + \text{Cl}\cdot$ [2].
COMMON ERROR The balanced overall equation in the stimulus is not itself one propagation step.

SECTION C HARDER MIXED ANSWERS

These answers expose the route, checks and linked chemistry needed for the higher-demand questions.

QUESTION 17 | HARDER MIXED

11 marks

- (a) R [1]. It has the lowest boiling range [1] and therefore condenses in the coolest, highest region [1].
 (b) Shortage of R = $34 - 20 = 14$ units and shortage of S = $51 - 42 = 9$ units, so combined shortage = 23 units [1]. Surplus of U = $70 - 35 = 35$ units [1].
 (c) Catalytic cracking [1] using a zeolite [1] to produce branched-chain alkanes/motor fuels [1].
 (d) $\text{C}_{19}\text{H}_{40} \rightarrow \text{C}_7\text{H}_{16} + 2\text{C}_6\text{H}_{12}$. [1]
 (e) Fractional distillation first separates existing molecules by boiling range [1]; cracking is a later chemical process that breaks C–C bonds and forms new molecules [1].

QUESTION 18 | HARDER MIXED

12 marks

- (a) $\text{C}_7\text{H}_{16} + 11\text{O}_2 \rightarrow 7\text{CO}_2 + 8\text{H}_2\text{O}$. Correct products and C/H balance [1]; O_2 coefficient [1].
 (b) The sample contains $0.100 \times 7 = 0.700$ mol carbon atoms. $n(\text{CO}_2) = 0.700 \times 0.700 = 0.490$ mol [1]; $n(\text{CO}) = 0.700 \times 0.200 = 0.140$ mol [1]; $n(\text{C}) = 0.700 \times 0.100 = 0.0700$ mol [1].
 (c) $n(\text{H atoms}) = 0.100 \times 16 = 1.60$ mol, so $n(\text{H}_2\text{O}) = 1.60 \div 2 = 0.800$ mol [1].
 (d) Oxygen atoms in products = $2(0.490) + 0.140 + 0.800 = 1.920$ mol [1]. $n(\text{O}_2) = 1.920 \div 2 = 0.960$ mol [1]. Correct unit and conclusion [1].
 (e) Restricted oxygen/incomplete combustion causes CO and carbon to form [1]. CO is toxic because it binds to haemoglobin and reduces oxygen transport [1]. Soot/particulates damage the respiratory system [1].

QUESTION 19 | HARDER MIXED

12 marks

- (a) $\text{Cl}_2 \rightarrow 2\text{Cl}\cdot$ [1]; ultraviolet light [1].
 (b) $\text{Cl}\cdot + \text{CH}_3\text{CH}_2\text{CH}_3 \rightarrow \text{HCl} + \text{CH}_3\text{CH}_2\text{CH}_2\cdot$ [2]. $\text{CH}_3\text{CH}_2\text{CH}_2\cdot + \text{Cl}_2 \rightarrow \text{CH}_3\text{CH}_2\text{CH}_2\text{Cl} + \text{Cl}\cdot$ [2].
 (c) $\text{Cl}\cdot + \text{CH}_3\text{CH}_2\text{CH}_3 \rightarrow \text{HCl} + \text{CH}_3\text{C}\cdot\text{HCH}_3$ [2]. $\text{CH}_3\text{C}\cdot\text{HCH}_3 + \text{Cl}_2 \rightarrow \text{CH}_3\text{CHClCH}_3 + \text{Cl}\cdot$ [2].
 (d) Propane contains hydrogen atoms in two different carbon environments [1], so substitution at an end carbon or the middle carbon gives different structural products [1].

QUESTION 20 | HARDER MIXED

12 marks

- (a) Route A uses 0.700 mol $\text{C}_{18}\text{H}_{38}$, giving 0.700 mol C_8H_{18} and 0.700 mol $\text{C}_{10}\text{H}_{20}$ [2]. Route B uses 0.300 mol $\text{C}_{18}\text{H}_{38}$, giving 0.300 mol C_6H_{14} and 0.600 mol C_6H_{12} [2].
 (b) Total alkene molecules = $0.700 + 0.600 = 1.300$ mol. [1]
 (c) Carbon atoms in products = $8(0.700) + 10(0.700) + 6(0.300) + 6(0.600) = 5.6 + 7.0 + 1.8 + 3.6 = 18.0$ mol [2].
 (d) Thermal cracking [1], using high temperature [1] and high pressure [1].
 (e) Catalytic cracking [1] using a zeolite catalyst [1].

SECTION D STRETCH / SYNOPTIC ANSWERS*Full-credit routes combine the Alkanes specification with secure prior quantitative and mechanism skills.***QUESTION 21 | STRETCH / SYNOPTIC****13 marks**

- (a) $n(\text{CO}_2) = 1.760 \div 44.0 = 0.0400 \text{ mol}$, so $n(\text{C atoms}) = 0.0400 \text{ mol}$ [1]. $n(\text{H}_2\text{O}) = 0.900 \div 18.0 = 0.0500 \text{ mol}$, so $n(\text{H atoms}) = 0.100 \text{ mol}$ [1]. $\text{C} : \text{H} = 0.0400 : 0.100 = 1 : 2.5 = 2 : 5$, so empirical formula = C_2H_5 [1].
- (b) Let the molecular formula be $\text{C}_{2k}\text{H}_{5k}$. For an open-chain alkane, $\text{H} = 2\text{C} + 2$, so $5k = 4k + 2$ and $k = 2$ [1]. Molecular formula = C_4H_{10} [1].
- (c) Butane. [1]
- (d) $2\text{C}_4\text{H}_{10} + 13\text{O}_2 \rightarrow 8\text{CO}_2 + 10\text{H}_2\text{O}$. [2]
- (e) $\text{C}_4\text{H}_{10} \rightarrow \text{C}_2\text{H}_6 + \text{C}_2\text{H}_4$. [2]
- (f) Butane has fewer electrons/a smaller electron cloud than octane [1], so its overall London (van der Waals) forces are weaker [1] and less energy is required to separate its molecules [1].

QUESTION 22 | STRETCH / SYNOPTIC**14 marks**

- (a) I initiation [1]; II propagation [1]; III propagation [1]; IV termination [1].
- (b) Ultraviolet light supplies energy to break the $\text{Cl}-\text{Cl}$ bond [1]. Homolytic fission gives one electron from the bonding pair to each Cl atom, forming two radicals [1].
- (c) Add II and III, then cancel $\text{CH}_3\cdot$ and $\text{Cl}\cdot$. Overall: $\text{CH}_4 + \text{Cl}_2 \rightarrow \text{CH}_3\text{Cl} + \text{HCl}$. Correct cancellation [1]; equation [1].
- (d) $\text{CH}_3\cdot$ is the organic intermediate [1]; $\text{Cl}\cdot$ is regenerated [1].
- (e) Steps V and VI replace another H in CH_3Cl by Cl and regenerate $\text{Cl}\cdot$ [1], so CH_2Cl_2 and still more highly substituted products can form [1].
- (f) Use methane in excess relative to chlorine to favour reaction of $\text{Cl}\cdot$ with methane/monosubstitution [1]. It does not guarantee purity because chloromethane still contains $\text{C}-\text{H}$ bonds and can undergo further substitution [1].